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Renewable and Sustainable Energy Reviews
9 (2005) 203–214
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

Sectoral energy consumption in Iran

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Received 17 February 2004; accepted 30 March 2004

Abstract

The gradual changes in the world development have brought energy issues back into high profile. An ongoing challenge for countries around the world is to balance the development gains against its effects on the environment. The energy management is the key factor of any sustainable development program. All the aspects of development in agriculture, power generation, social welfare and industry in Iran are crucially related to the energy and its revenue. The impact of energy production, distribution and consumption grows more severe with every decade. The growing number of people predicates a rapid growth in demand in the coming years. In order to ensure a sustainable path of development, it is necessary to find a way to reconcile production and consumption with its impact on natural resources. The emphasis should be placed on the development, implementation and transfer of cleaner, more efficient technologies. Iran is on the rising energy intensity curve. We have to learn from the experience of other developed countries and make the necessary transition towards sustainable management of natural resources.

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1364-0321/$ - see front matter
doi:10.1016/j.rser.2004.03.002

1. Introduction

Energy enters our everyday lives in many different ways. For society to function in its present patterns and make progress, vast amounts of energy are consumed [1]. Much of the energy is produced and consumed in ways that cannot be sustained. The problems of energy are complex and go far beyond the question of immediate availability of motor fuel. As the living standards of citizens in developing countries improve, many energy related problems are becoming more severe with passage of time. However, a huge consumption gap exists between industrialized and developing countries. Any non-renewable energy related development has environmental consequences. Beyond the supply side of the energy problem, the effects of emissions on the local and global atmosphere [2] are obvious. Providing a solution to environmental problems that we face today requires long-term actions for sustainable development [3].

Petroleum and natural gas are the most important primary energy source in Iran. Iran's economy is dependent on export of oil and natural gas. Iran has 9.2% of the total oil reservoir, and is placed at the fifth position after Saudi Arabia, Iraq, UAE and Kuwait. Iran's role among the Middle East oil producer has been that of a pioneer. Iran is the oldest Middle East producers, the first to nationalize its oil industry, the originator of the national oil company concept [4].

Iran's primary energy resources seem to be plentiful. As Iran's economy has expanded since the flow of oil revenue, the consumption of primary energy has been increased. With a population of 67 million, it is necessary to develop infrastructure capable of utilizing the oil revenue [5]. Iran's geographic location has several advantages for the extensive use of the renewable energy sources. Solar radiation is widely available over the entire region. The average solar energy is about 2000 kW h/m^2. The average number of sunshine hours is about 2800 h/year. In the central part of Iran which has a hot dry climate, the total solar energy is much higher than 2000 kW h/m^2 with an average of 3200 sunshine hours per year [3].

2. The energy situation

Iran's primary energy sources include oil, natural gas, electric power (three-quarters or more was natural gas-fired, with the remainder either being hydroelectric or oil-fired), solar, wood, animal and plant waste. Oil and natural gas are the major source of primary energy in Iran. The known oil reserves are estimated to be about 90 billion barrels. The major oil field of Iran is located in the southwest region and in the Persian Gulf. Iran produced about 3.5 million bbl/d of oil during 2002. Iran's current sustainable crude oil production capacity is estimated to be at around 3.75 million bbl/d. The domestic oil consumption is about 1 million bbl/d in 2002. Iran's oil export was about 2.5 million bbl/d in 2002, of which 28% of went to Europe, 20% to Japan, and under 10% to South Korea, and other large customers including China and India [6]. Iran's domestic oil consumption has been

increasing rapidly as the economy and population grow (about 7% per year). The price of oil products is heavily subsidized to the tune of $ 3 billion or so per year [6]. This causes a large amount of waste and inefficiency in oil consumption; in addition, a substantial amount of petroleum products (mainly gasoline) is also smuggled to the neighboring countries since petroleum products are much cheaper in Iran than in neighboring countries. Iran also imports around $1 billion per year worth oil products (mainly gasoline), which it cannot produce locally. Gasoline price is raised by 30–35% every year in early April. This is a part of an effort to curtail the rise in gasoline subsidy expenditure, gasoline consumption and imports (both are growing rapidly). The consumption trend is expected to continue in an unsustainable manner [7]. Besides public awareness of energy conservation methods, domestic supply and demand may be balanced by changing the price structure of oil products in Iran. Since Iran has nationalized her oil resources, there is a general feeling among people that the government should ensure that oil products are available to the public at lower prices.

There is an impressive amount of natural gas in the reserves of Iran. Iran is in the second position after the former USSR. The known reserves of Iran are about 35.4 tcm (trillion cubic meters), which account for 16% of the world's total known reserves [4]. The total recoverable natural gas reserves of Iran are about 26.57 tcm. Around 62% of Iranian natural gas reserves are located in non-associated fields which have not developed yet. Therefore, Iran has a huge potential for the gas industry development and could be a major natural gas exporter as well. Iran's natural gas production was 2.6% of the total world production in 2002. The average gross annual production rate is about 13.1% in the last 10 years. It is planned to increase production to 62 mcm/d (million cubic meters/day) in the next Five Year Plan. One of the major hindrances to wider use of natural gas in different sectors is the lack of extensive pipeline system for transport and distribution in small cities and towns. The expansion of natural gas distribution system and transport networks is one of the major policies in the energy section [8]. Natural gas transport network has been expanded on average of 940 km/year since 1996 and about 19 projects have been undertaken to add 2034 km to the transport network system. The pipeline distribution system for domestic and industrial uses has been extended to 396 cities, towns and villages in the last three years and a total of 69 071 km of pipeline has been laid since 1981 to bring natural gas to the consumer. Currently, natural gas accounts for nearly half of Iran's total energy consumption and the government plans billions of dollars worth of further investment in the coming years to increase this share. It is ultimately planned to replace oil product consumption by natural gas in the household and industrial sectors. In the international natural gas trade, Turkey, Ukraine, Europe, India, Pakistan, Armenia, Azerbaijan, Taiwan, South Korea, and coastal China are potential markets for Iran's natural gas export [8].

Gross electricity production in Iran reached 28 GW in 2002. The steam-powered units are a source for 54.4% of electricity production, 25.1% natural gas-fired, 14.5% combined cycle, 7.1% hydroelectricity, and 1.9% oil-fired. A number of new power plants (mainly hydroelectric and combined cycle) have come on line in

recent years in Iran, as a result of significant state investment in this area. This includes the 2000 MW Shahid Rajaei thermal power station in Qazvin; a 1290 MW combined-cycle plant in Rasht; a doubling of the Tabriz Power Plant's capacity to 1500 MW; two, 200 MW, steam-powered units at the Martyr Montazeri plant; a 215 MW steam-powered unit at the Ramin Power Plant; a 107 MW combined cycle generator at Montazer Qa'em Power Plant, and three-quarters of the Shazand Power Plant near Arak in Central Iran. Electricity consumption in Iran reached 1532 kW h/person in 2002. It is planned to add 30 GW of thermal and hydroelectric power generation capacity to the power generation system within the next 10 years. It is expected that 3 GW will come on line by the end of March 2004. The 1040 MW combined cycle plant in the south, an 1100 MW combined cycle plant at Arak, and a 1000 MW combined cycle plant in Bandar Abbas are the new thermal power projects. The largest hydropower projects are the 3000 MW Karun 3 plant, the 2000 MW Godar-e lander facility, a 1000 MW station in upper Gorvand, and the 400 MW Karkheh dam. The Kerman 1272 MW combined cycle plant came on line in February 2003. It is also planned to build the first 100 MW geothermal power plant in the northwest province of Ardebil [9]. This project is expected to be completed in 2006 and so far 25% of this project has been completed.

Coal is found in three major regions of Iran: the Tabas Basin with 4500 million ton, the Alborz Basin with 552 million ton and the Kerman Basin with 315 million ton. Coal is mainly used for steel-making and cement production. It was also used for electric power generation earlier. Oil and natural gas quickly replaced coal in power plants. A total of 1.7 million ton of coal was produced from 101 mines in 2001. It was planned to increase coal production to 3.5 million ton in 2003. Since the quality and standard of domestically produced coal does not meet the required standard of the steel making industry, a certain amount of coal is exported from Australia. The imported coal is mixed with the domestically produced coal and is used in steel-making industries. About 489×10^3 tons of coal was imported in 2001 and 116.2×10^3 tons of produced coal was exported to Turkey [10].

Iran's renewable energy consumption is low. The abundant supply of fossil fuel resources and natural gas reserves discourages the pursuit of renewable energy. The gross hydroelectricity production in Iran is about 1998.5 MW, which is 7.1% of the total electricity production. It is planned to increase hydropower capacity to 17 364.5 MW by completion of several hydro power plants. Currently, the largest hydropower projects are the 3000 MW Karun 3 plant, the 2000 MW Godar-e Landar facility, the 1000 MW station in Upper Gorvand, and the 400 MW Karkheh dam [9]. The Wind potential has been studied in 45 experimental sites at 26 areas of Iran. It was found that the gross wind energy potential of Iran is about 6500 MW with an average speed of 5 m/s. Fifty percent of this potential is technically feasible. Construction of two wind power plants with a capacity of 25 and 60 MW in Manjil will be started in 2004 with the help of the World Bank and Japanese government loans. The Atomic Energy Organization of Iran installed 39

experimental wind turbines with a total power generating capacity of 12 MW at Manjil and Harzwhel areas [5].

The daily average solar energy is about 4 kW h/m^2 in Iran, and the total yearly average radiation period is above 2800 h, which provides adequate energy for solar thermal application. Solar energy for agricultural grain drying and hot water heating has been in use in the country for many years. Domestic water heating system is a primary active solar technology. The Ministry of Energy has installed several solar water heating systems in rural areas of Iran under the renewable energy development program. Under this program, 30, 10 and 5 kW photovoltaic (PV) systems are also installed in hot and dry rural areas of Iran. The potential of Iran as a PV market is very large, since the country is quite suitable in terms of insolation and availability of large areas of land for solar farms [5].

Biomass in the form of fuel-wood and animal wastes is the main fuel for heating and cooking in the rural areas of Iran. Fuel-wood is important in rural areas in Iran as in other developing countries. The total forest area in Iran is about 12.4 million ha. Forestry operations are an important source of employment in the rural areas. A total of 1.2 million m^3 wood products were mainly produced from the forests of Gilan, Golastan and Mazandran provinces of Iran in 2001 [10]. In the last few decades as population growth has peaked, deforestation rates have reached to the highest level in the last two decades.

3. The sectoral energy production and consumption

Iran's primary energy includes oil, natural gas, hydroelectricity, wood and animal wastes. Iran's primary energy consumption is increasing rapidly as the economy and population grow, as shown in Fig. 1. The global total primary energy

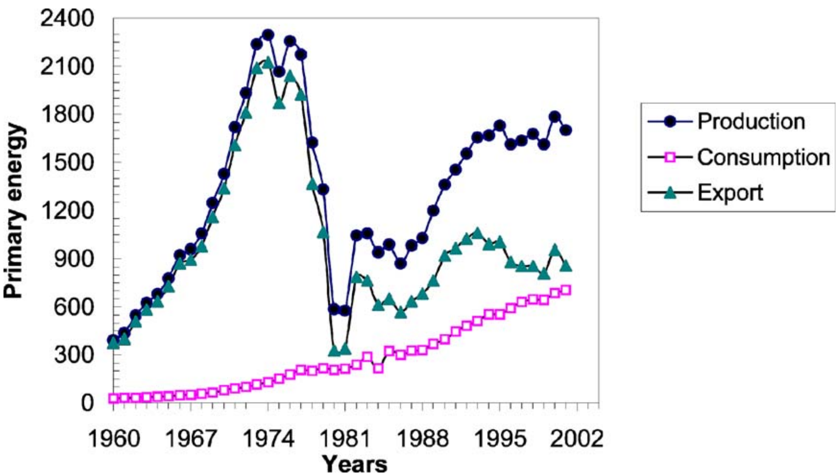


Fig. 1. Iran's primary energy production, consumption and export (million barrels oil equivalent).

Table 1
Pattern of energy demand in Iran (million barrels oil equivalent)

Year	Petroleum products	Natural gas	Solid fuel	Electricity	Total
1960	22.7	6.7	7.2	0.2	36.8
1965	34.5	7.5	5.9	0.95	48.8
1970	60.7	10.2	5.4	3.6	67.4
1975	118.5	15.0	11.9	8.0	137.2
1980	171.5	12.9	11.3	11.3	193.2
1985	264.6	30.3	9.9	20.0	311.3
1990	284.6	74.9	7.9	29.6	364.1
1995	345.1	172.4	11.5	40.5	534.4
2000	382.7	238	10.7	56.7	650.7

consumption has been increasing in the last 42 years (1960–2002) at an average annual rate of 5%. The study of population growth and primary energy consumption shows that in the last three decades, the amount of primary energy equivalent to 1.6 barrels of oil per person per year in 1960 has increased to 12.7 barrels of oil per person per year in 2002. This trend is expected to continue unless energy conservation techniques are employed in some sectors [11]. The energy demand is dominated by petroleum products and natural gas in Iran. Hydroelectricity, coal, wood and animal matter have subordinate roles. Table 1 shows the pattern of energy demand in Iran for selected years.

Table 1 shows that petroleum products consumption has continuously been increasing since 1960. There were some uncertainties in production and consumption from 1978 to 1980 due to the 1978/1979 Revolution (Fig. 1). The consumption trend has then been regularly increasing from 1980. Iran produced about 3.5 million bbl of oil per day during 2002; about 1 million bbl/day was consumed with a net export of around 2.5 million bbl/day. Since the formation of Iranian National Oil Company (NIOC), the government has been heavily subsidizing petroleum product price in order to provide a cheap energy source for the industrialization process in Iran. This amount has reached $3 billion or so per year [12]. A large amount of waste and inefficiency has occurred in the petroleum product consumption. As a result, an acute imbalance is always observed between the pattern of supply and the structure of demand. The government is forced to import petroleum products (mainly gasoline) to the tune of $2 billion per year to meet domestic demand. Energy consumption in transport section ramped up from 78 million bbl in 1980 to 195 million bbl in 2001, almost two and a half-fold increase. Much of this energy is accounted for by gasoline consumption. In Tehran, 11 million l of gasoline are consumed daily by 2.5 million cars. Most of Tehran's 2.5 million cars are over 20 years old with leaky engines and poor fuel efficiency. The cheap cost of the subsidized petroleum products deprives car producers of incentives to make them fuel-efficient. On the other hand, higher fuel prices would bring the per kilometer cost of driving for people above what they have experienced in the past without any technical improvement in the common-people car.

Tehran with 28% of the total gasoline consumption has the highest share of gasoline consumption among cities in Iran. The transport sector has the highest rate of petroleum product consumption with a growth rate of 8% [13]. The household and commercial sectors are the second major petroleum product consumer. The consumption of oil in the household and commercial sectors had a negative growth rate of 2.3% in 2001 since more clean-burning natural gas was substituted for oil. The industrial and agricultural sectors rank third and fourth in the petroleum product consumption. The overall consumption of petroleum products has increased by about 3.6% in 2002 with respect to that of the previous year.

With easy availability of natural gas, LPG and electricity, the consumption of kerosene has decreased in recent years, at an average rate of 2.3% per year. Kerosene is mainly used (98%) for heating, cooking and lighting in household and commercial sectors. The average consumption of kerosene is 1000 l/year per family.

Fig. 2 shows Iran's energy consumption during 1960–2000. The major natural gas consumption in 1960s and 1970s was in oil production and as a refinery fuel. The share of natural gas in oil production had declined to nil during 1980–1988 due to eight years of the Iran–Iraq War. In the domestic energy, the consumption was almost nil till 1971, and it gradually picked up in the 1970s and 1980s. With the completion of laying pipelines in large cities, the consumption of natural gas had been rapidly increased in the 1990s [14]. The share of natural gas in the household sector consumption of primary energy has exceeded that of oil products since 1998. The economic and environmental benefits of natural gas and uncertainty in oil export (Figs. 1 and 2) provide impetus to increase its share in the household sector. Currently, half of Iran's total energy consumption comes from natural gas. The government plans billions of dollars of further investment in the coming years to increase the share of natural gas in domestic energy consumption. Natural gas consumption has increased in household and commercial, industry, power plant, and refinery by 51.7%, 49.4%, 69.8% and 63.2%, respectively, from 1996 to 2002

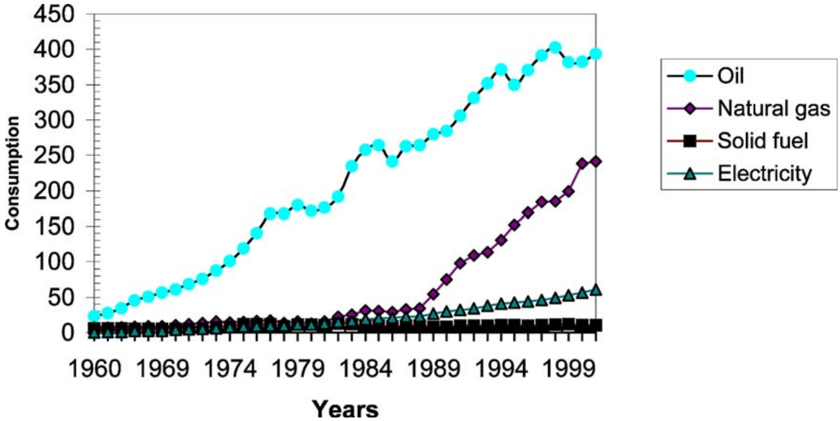


Fig. 2. Iran's energy consumption (million barrels oil equivalent).

[15]. The consumption of natural gas in household and commercial sectors has been growing rapidly as the distribution pipeline extends into different provinces of Iran. Natural gas is used for lighting, water and space heating and cooking in the domestic sector. Natural gas is also used in refineries for water heating, steam and hydrogen production. Gas has become an increasingly popular option for electricity generation in recent years since gas is relatively cheap as compared to oil. The combined cycle gas turbines are very efficient and are used in all new power plant stations in Iran. The consumption of natural gas is negligible in agriculture and transport sectors. Gas burning technology has enormous potential in Iran and is certainly becoming commonly used.

Iran's total electricity generation was about 124 GW h in 2001 with a growth rate of 7.4% with respect to that of the previous year [16]. It is expected to increase at a rate of 9% per year. Export of electricity has been reduced to 305 MW h in 2001 as compared to 722 MW h in 2000. According to the Ministry of Energy forecasts, 28 GW electricity should be added to the present 28 GW generation capacity in order to meet electricity demand in the next 10 years. It is planned to generate 8 GW from hydroelectric power plants and 22 GW from thermal and combined cycle power plants. Household, public, commercial, industrial and agricultural sectors account for 35%, 13%, 7%, 31% and 11%, respectively, of electricity consumption. The total electricity consumption was about 102.8 GW h in 2001. This includes the power generated from private power units in industries and agriculture sectors which comes to around 5.8 GW h. Electricity consumption rate had increased in the agriculture sector by 10.3% in recent years. Electricity consumption in Iran increased to 2015 kW h/person in 2001. Main attention should be given to household use. Buildings and appliances use 35% of the total electric energy produced in the nation. The maximum household energy use in Iran is for space heating, cooling and lighting.

4. Pattern of energy use and development

It is generally agreed that there is a close correlation between the rate of economic growth and the demand for energy. Government policy and the way it affects the direction of the economical growth had an important influence on the demand for oil products and natural gas. Petroleum products and natural gas have a dominant role in the pattern of energy use in Iran. Table 2 shows the energy intensity (energy consumption/GNP) for five distinct periods in Iran.

In the period 1960–1969, economy was affected by recession in the first three years, and later on, it showed signs of recovery (Fig. 1). Energy growth rate was about 10% in this period. Oil revenue increased and economic growth rate began by the end of this period [17]. The history of consumption and production of primary energy in Iran is shown in Fig. 1 since 1960. In the period 1960–1969, the total energy consumption was about 5.6% of the total energy production. Iranian population was about 29 million with 35% being the urban population. The economy of Iran was agriculture-based economy during 1960–1969.

Table 2
The growth rate of GNP and energy demand (%)

Years	Gross rate of national product (GNP)	Energy consumption growth rate	Ratio of energy consumption to GNP growth rate
1960–1969	7.6	10.9	1.4
1969–1979	11.8	11.6	0.98
1979–1989	−3.3	6.0	−1.8
1989–1999	3.2	8.4	2.6
1999–2009[a]	3.2	5.0	1.5

[a] Projected GNP and energy consumption growth rates are predicted based on the average growth rates of 3.2% and 5% in the last 34 years, respectively.

Economic progress was in full swing during 1969–1979 (Fig. 1). The stability of the political system attracted foreign and domestic capital to set up industries that were naturally petroleum based. Most of the foreign debt was repaid after the sudden increase in oil price in 1973. In this period, 86% of the total foreign exchange requirement came from oil revenues [17], as shown in Fig. 1. The growth rate of energy demand and GNP were about 11.8% and 11.6%, respectively, during this period. The ratio of energy consumption rate to GNP growth rate was about 1; it was similar to that of the industrial countries. This indicated rapid economic progress and immense utilization of energy resources. In this period, population and industrial growth rate had increased several folds as compared to that in the period 1960–1969. The population of Iran was over 34 million in this period. The Iranian urban population rose to 45%. The growth in urbanization affected the demand for oil products (Fig. 2). Industrialization on a massive scale was started and work forces came from rural areas to big cities. The total energy consumption increased to 6.6% of the total energy production during the 1969–1979. Oil consumption increased at an average rate of 14% during the period 1969–1979. The transport sector had the highest share of oil consumption toward the end of this period.

The period 1979–1989 was marked by a severe economic crisis, a slow down in industrial activity combined with the eight years of Iran–Iraq War which adversely affected the economic growth rate. Oil and natural gas production reached its lowest level in the last 19 years (1.5 million bbl/day) and the share of non-oil export also declined, as shown in Fig. 1. In this period, Iran's foreign exchange requirements were far above the net oil export income and Iran's ability to borrow internationally was also very limited. All development planning was stopped due to a shortage of foreign exchange requirement. The population of Iran increased to 51.3 million, with the urban population rising to 56%. About 29% of total energy produced was accounted for by the domestic energy requirement during this period. During the period 1979–1989, the household and commercial, transport and industry share of total energy consumption were 30.6%, 31.3% and 23.7%, respectively.

During 1989–1999, the plunge in oil prices in 1998 and early 1999 hit Iran's economy hard. The imposed sanction in 1995 also affected the oil and natural gas

industries during this period. Despite all these hardships, financial pressure eased in Iran due to a strong market in 1996. Iran could set up an oil stabilization fund due to relatively high oil export revenues. Iran's population reached 62.7 million with the urban population rising to 61% during this period. About 33.7% of the total primary energy produced was consumed in the domestic market during this period. The consumption of natural gas has been growing in the household, commercial and industrial sectors since 1989, as the natural gas distribution network expanded to the cities and industrial centers. The share of household, commercial and industry sectors from the total petroleum products consumption has reduced to 28.7% and 16.5% since 1989. The share of transport sector from the petroleum product consumption has increased to 39.3% since 1989. The overall consumption of petroleum products has decreased by 3% since 1996 as more clean and cheap natural gas has substituted oil in household, commercial and industrial sectors. The ratio of energy consumption to GNP growth rate was about 2.6. It is expected that the ratio of energy consumption rate to GNP growth rate will reach 1.5 during the 1999–2009 period with large investment in oil, natural gas, industry, mines and in the development of infrastructure.

Iran's average crude oil export has been about 932.2 million bbl/year since 1992. Iran produced 6 million bbl/day in 1974, but has not surpassed 4.6 million bbl/day on an annual basis since 1979, as shown in Fig. 1. About 80% of total exports earning, 40–50% of the government budget and 10–20% of GDP rely on oil export revenues. The present production capacity cannot be sustained without major gas injection secondary recovery methods. Thus, valuable quantities of gas must be used to sustain the productivity of the oil fields. To what extent this gas-for-oil exchange is economically rational may be subject to future oil market trends. It is of prime importance to sustain and increase the crude oil export capacity. It is planned to increase oil production to about 5.6 million bbl/d by 2010 and 7.3 million bbl/d by 2020. At present, the national energy consumption is at an alarming rate, and due to limited production capacity, the government is trying to maintain its oil export rate by implementing energy conservation techniques in all sectors. Since 1995, several sizeable oil resources have been discovered in different locations of southwestern province of Khuzestan. Iran can increase its oil production capacity with the help of foreign investment in the new oil discoveries. It is estimated that an investment of $5 billion per year is required to boost oil production. Foreign companies through buyback contracts took part in the development of petroleum resources in Iran. By creating more favorable conditions, more financing of oil projects is expected to come from foreign companies.

Energy conservation techniques are also beginning to have an impact in some sectors. The development of more energy efficient products like low energy refrigerators, cookers, TVs and computers made great strides in the energy conservation program. Energy efficient lighting is currently a major area of interest in the household and commercial sectors. The share of solid fuel like wood, coal and animal matter has declined in the household sector energy consumption. Energy conservation education has also been started in industries since energy saving is impressively large. Programs of education and persuasion are needed in an industrial

setting. However, energy use in the transport sector has also been increasing in Iran. Along with the implementation of energy conservation policy in different sectors, the development of renewable energies has been carried out under different programs with government planning agencies working closely with private sector companies and universities. The Office of Renewable Energies in the Ministry of Energy has started various R&D projects in the geothermal, solar heating and power, hydroelectric power, wind power sectors.

5. Conclusions

The consumption of petroleum products has increased from 22.7 million bbl/year in 1960 to 392.9 million bbl/year in 2002. The population has increased from 22.9 million in 1960 to 65.5 million in 2002. While Iran's population has been more than doubled (2.8 times) in 42 years, the per capita oil consumption rose steadily from 1 to 6.0 barrels per person per year. The household, commercial and transport sectors are the main users of petroleum products in Iran. There is clearly a close relationship between the level of economic development and demand for energy in all countries of the world. The government strategy on industrialization, economic growth, expansion of domestic distribution network, population growth rate, urbanization and increase in per capita income has significantly contributed to rise in energy demand. The present domestic energy demand growth rate is very high. It has also significantly contributed to pollution level. More clean-burning natural gas is substituted for oil in household, commercial, industry and agriculture sectors. It accounts for nearly half of the total national energy consumption. Oil revenue is very important for the economic growth of Iran. In order to maintain oil revenue, crude oil production capacity has to be increased by upgrading and modernizing oil industry. The government policy has been so far to produce more oil and increase the oil refineries' capacities to meet the growing demand of end-use markets predominated by the transport, residential, commercial and industrial sectors. The imbalance between the refineries supply pattern and the demand for oil products in Iran has particularly become important since 1980s. Iran's rising population requires the definition and implementation of sustainable energy and development policies. The share of non-oil exports in foreign exchange receipts has to be increased in any sustainable development plan, as the share of domestic energy demand increases in the total energy production. As a developing country, Iran is on the rising energy intensity curve. We have to learn from the experience of other developed countries and make the necessary transition toward sustainable management of natural resources. It is also necessary to support clean energy efficient technology transfer to the developing countries in a global move toward sustainable development. The transition of developing countries to the post-industrial economy is the most important global issue in order to make a global attempt toward a steady state economy and pattern of consumption.

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